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Review of Research on Hydraulics of Ship Lift Car

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Abstract

Because the shallow water effect and shore wall effect have significant influence on the ship's hydrodynamic force during the movement of ship in and out of the ship lift car, the operation process of the ship lift at this stage is more complicated and there are many influencing factors, which is one of the core links of the safe operation of the ship lift. Therefore, based on domestic and foreign research data, this paper analyzes and summarizes the types of ship lift and the hydrodynamic characteristics of ship lift during the phase of ship entering and exiting the car, and summarizes and prospects: specific issues such as the characteristics of water surface fluctuation in the car during the process of ship entering and exiting the car, the amount of ship sinking, the relationship between water surface fluctuation and ship speed have been studied in detail. Physical model tests are still the main research on the water surface fluctuation characteristics during the process of ship entering and leaving ship compartments. In the numerical simulation of ship entering and leaving ship compartments, two-dimensional numerical simulation is the main research, which can be multi-directional three-dimensional simulation research. There is also a lack of specific research and analysis on the fluctuation characteristics of the water surface in the process of entering and leaving the hull of the vertical ship lift.

Keywords

Ship Lift; Hydrodynamic Force; Cabin.

1. Introduction

The main function of navigable buildings is to ensure shipping, so that ships can smoothly pass through the dam section caused by the construction of water conservancy projects. In water conservancy projects, navigable buildings play a good role in ensuring the normal shipping of ships, and are an indispensable part of hydraulic buildings. Navigable buildings mainly fall into two categories: lock and ship lift [1]. Ship lift is a kind of navigable building that lifts or lowers the ship through hydraulic or mechanical devices to overcome the water level difference [2]. Through the ship lift, the ship can quickly rise or fall from the initial water level to the target water level, compared with the lock, the ship speed is the most obvious and the biggest advantage; And in addition to the advantage of "fast", compared with the ship lock, the ship lift in the process of lifting the ship almost does not need to consume water resources, in part of the water shortage in the river, the ship lift has obvious advantages. Ship lift, as a navigable building with less water consumption and fast running speed, plays an indispensable role in realizing the smooth flow of inland navigation [3].

The process of ship lift in the air is usually simple, smooth and smooth. In the stage of ship lift docking with upstream and downstream ships entering and exiting the ship lift, because the ship lift is generally in the form of a car structure, in order to reduce the dragging power of the ship lift and reduce the engineering cost, the determined section coefficient of the ship lift is small, and the blocking effect is very obvious when the ship enters and exits the ship lift [4].

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Due to the size limitation of the ship compartment, the shallow water effect and the shore wall effect have a significant impact on the ship's hydrodynamic force during the movement of the ship in and out, resulting in a relatively complicated operation process of the ship lift at this stage with numerous influencing factors, which is one of the core links of the safe operation of the ship lift [5]. Therefore, based on the research data at home and abroad, this paper summarizes the types of ship lift and the hydrodynamic characteristics of ship lift during the phase of ship entry and exit.

2. Ship Lift Type

According to the different route of the ship car, the ship lift can be divided into vertical ship lift and inclined plane ship lift two kinds. For these two forms of ship lift, it can be divided into a variety of different types according to whether the weight of the ship carriage is balanced by the balance weight, whether it holds water, whether it is launched and how it is driven [6]. This paper is subdivided into more forms according to different body lifting principles and safety early warning mechanisms, the specific forms are described below.

2.1. Vertical Ship Lift

Vertical ship lift refers to a class of ship lift whose working path of the body structure is vertical rise or fall. According to the working principle of the device, this type of ship lift can be further subdivided into three forms: balanced weight ship lift, float ship lift and hydraulic ship lift.

The working principle of the counterweight vertical ship lift is to balance the weight of the ship carriage and the weight of the water body by the weight of the counterweight, and to lift the structure of the car body by the way of the lifting mechanism. According to the different lifting methods, it is mainly divided into two categories: wire rope hoisting type and rack and pinion climbing type. The main difference between the two is that the power system and the safety warning device are different. The steel wire rope hoisting vertical ship lift adopts the hoisting machine as the power system. The two ends of the steel wire rope are connected to the balance weight and the ship carriage structure respectively, and the steel wire rope is tightly wound in the middle of the drum to prevent it from slipping during the working process. When the hoisting machine begins to work, the drum rotates to drive the steel wire rope to rotate, and then the car body structure does the lifting movement. The reliability of the action of the safety device for preventing water leakage in the ship cage of the wire rope winching and lifting ship lift depends on the accuracy and reliability of the relevant detection, monitoring and control signals, and has high requirements for the working reliability of the ship cage wire rope equalization system and the reliability of the safety brake [7]. Rack and pinion climbing ship lift is a type of vertical ship lift developed in our country in recent 10 years, which has been used in the Three Gorges ship lift [8] and Xiangjiaba ship lift [9]. The main feature of the rack and pinion climbing vertical ship lift is that the gear mounted symmetrically on both sides of the ship car engages with the rack on the tower column to drive the ship car up and down, and the symmetrical driving mechanism is connected by a mechanical synchronous shaft. The deformation of the tower structure has a direct impact on the normal operation of the ship lift. In case of accidents such as water leakage during the lifting process, the drive mechanism will stop by itself and the ship compartment will be locked by the safety mechanism.

The working principle of the buoy vertical ship lift is that the buoy device is set at the lower part of the boat tank, and the buoy is placed in the shaft structure, so the boat tank can move up and down with the float. Compared with the counterweight type ship lift, the float type ship lift is simple and clear because it eliminates the hoist, wire rope and counterweight equipment, and the safety during operation is obviously improved. From the end of the 19th century to the 1960s, the Germans designed and built several floating vertical ship lifts [10]. The buoy of the ship lift is placed in the shaft, the top of the shaft is provided with a manhole cover, and the

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support installed on the top of the buoy is hinged with the bottom of the ship compartment through the hole reserved on the manhole cover. The buoy is divided into two isolation silos, the upper and the lower, and is filled with compressed air. A balance silo with the lower end open is set in the lower isolation silo of the buoy. When the buoy sinks, the air in the balance silo is compressed by water, and the water pressure decreases when the buoy rises, and the air in the balance silo expands to offset the buoyancy change caused by the support being exposed or submerged in the water.

The working principle of hydraulic vertical ship lift is to balance the body structure and the body weight of the water body through the water pressure acting on the bottom of the piston, in order to achieve the purpose of supporting the ship. The ship lift must be designed as a two-wire structure, the two lines of the structure maintain balance with each other, when one side of the ship car rises, the other side of the ship car falls accordingly, the two lines of pistons are connected through the culvert pipe to form a water pressure balance, the use of the two lines of the ship car to pour a small layer of water to form a weight difference, under the action of the driving mechanism to guide the ship lift to work, the driving mechanism uses very little power. However, the sealing device between the piston and the piston well is easily damaged, and this kind of ship lift is no longer built in modern times.

2.2. Inclined Plane Ship Lift

Compared with vertical ship lift, inclined plane ship lift has the advantages of saving transportation costs, reducing engineering investment, avoiding complex technical problems caused by high-altitude buildings, and having no big problems in design and operation [11]. The biggest feature of inclined plane ship lift is that the ship lift runs along the pre-laid track on the inclined plane, so the ship transport device is usually designed as a ship carrier, which runs along the track laid on the inclined plane under the drive of the power device. At present, the number of inclined plane ship lift has been built in the world is very small, but there are some examples of large transport volume. For example, the inclined plane ship lift located in the Krasnoyarsk hydropower Station in Russia is world-famous for its design of a transport ship with a weight of 3,000 tons [12]. Similarly, according to the motion form of the ship lift, the inclined plane ship lift can also be further subdivided into three types: longitudinal wire rope winch towed inclined plane ship lift, horizontal wire rope winch towed inclined plane ship lift and longitudinal self-climbing inclined plane ship lift.

The structure of longitudinal steel wire rope winch towed inclined plane ship lift is mainly composed of three parts: ship carrier, approach channel and track laid along the inclined plane. The ship lift is a ship transport device, which is basically equipped with a counterweight device to balance the weight of the ship lift and the water body. The setting of the counterweight can well reduce the driving load of the power mechanism and ensure the safety of the ship lift during work. As the main components of the ship lift structure, the upper and lower approach channels usually play a role in connecting the upstream and downstream river channels and the ship car. At the same time, the setting of the approach channels is a good barrier to the fluctuation of the water level of the natural river, ensuring that the ships can enter and exit the ship truck structure smoothly. The track laid along the slope is the basis for the operation of the ship carrier, similar to the railway track, it can guide the vehicle along the fixed route to ensure that the route will not appear large deviation and other accidents. In addition to the above three parts of the main structure, the inclined plane ship lift is also equipped with some auxiliary facilities according to the operation needs, such as the tension device installed on the ship carrier, the steel wire rope connecting the ship carrier and the balance weight, and the power mechanism driving the ship carrier.

Comparing the transverse winch towed inclined plane ship lift with the longitudinal winch towed inclined plane ship lift, the two are completely consistent in terms of composition

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structure and operation procedure, the only difference is that the direction of travel of the ship lift is different, the direction of travel of the longitudinal inclined plane ship lift is consistent with the direction of the approach channel, while the horizontal type is vertical with the direction of the approach channel.

The specific composition of longitudinal self-climbing inclined plane ship lift is basically the same as the previous two forms of inclined plane ship lift, the main difference is that the driving principle of self-climbing inclined plane ship lift is different, similar to vertical rack and pinion ship lift, longitudinal self-climbing inclined plane ship lift is provided with a gear mechanism on both sides of its ship carrier in advance. And the gear mechanism and the rack mechanism installed on the ramp completely bite, and a ramp type turntable is arranged on the upper part of the ship lift to adjust the direction of the ship. It is precisely because of the setting of the turntable that the ship lift truck of this type is usually designed as a unilateral open form.

3. Physical Model Test Research

Based on physical model research, Nanjing Institute of Hydraulic Science [13] analyzed the hydraulic characteristic values of ships entering and leaving the car, such as longitudinal eccentricity formed by water fluctuation in the car and the sinking amount of the ship. Gu Zhenghua et al. conducted a physical model test on the hydrodynamic characteristics of the ship lift under different working conditions, and carried out a theoretical analysis of the ship's longitudinal force. By comparing with the test data, a simplified mathematical model of the ship's force was established. It is found in the test that the ship blocking effect is also conditional when there is a ship in the chamber, and the blocking ratio also has a peak point, which can be regarded as the lower limit for dividing restricted waters [14]. Zheng Baoyou et al. conducted a navigation condition test on the middle channel of Longtan ship lift and obtained the relationship between speed and water level fluctuation in the channel. The results showed that water level fluctuation at different positions along the middle channel increased with the increase of speed [15]. Through physical model tests, Zhang Ruikai [16] studied the hydrodynamic characteristics of ships entering and leaving the ship under conditions of different ship types, ship depth and speed, including the maximum sinking capacity of the ship, water surface fluctuation in the ship entering and leaving the ship, and changes in the longitudinal moment of the ship. The results show that the distribution law of water surface fluctuation value in the ship entering the car is opposite to that in the ship exiting the car. The fluctuation amplitude of water level in the ship moving closer to the closed end of the car is larger, and the maximum longitudinal tilt moment value of the car increases with the increase of the ship exiting speed. Li Yan et al. [17] used two ship models of traction and self-propulsion combined with hydraulic physical models to test and analyze the navigation hydraulic characteristics of ships in the middle channel of Guopitan ship lift. The relative relationship between speed and navigation resistance, ship subsidence and water surface fluctuation in the channel is obtained. The test results of water surface fluctuation show that the rise and fall of water level in the ship compartment are positively correlated with the ship speed at different speeds, and are greater than other parts.

Based on the physical model, Tian Yanbo [18] analyzed the hydraulic characteristics of the ship's entrance and exit compartments of ship lifts, and concluded that the ship's exit velocities cannot be restricted by the same standard, but should be restricted according to different section coefficients and different ship categories. Li Zhonghua et al. [19] studied the variation law between the maximum sinking amount of a ship entering and exiting the ship lift hull and the water depth of the hull, the ship speed and the section coefficient of the hull by using a physical model of 1:16. It is proposed that the process of exiting the ship is the control condition of the design depth of the ship, and the dimensionless calculation formula of the ship sinking is established. The reasonable design water depth standard of Xiangjiaba ship lift is put forward by comparing the sinking capacity of ship and the safe depth of ship bottom with different water depths. Wang Jingpeng et al. [20] conducted a systematic study on the bottom edge forms of the main body of the launching ship lift through a generalized physical model of the water entry and exit process of the boat with a scale of 1:20, and discussed the effects of different bottom edge forms of the boat on the water surface fluctuation, adsorption force, flapping force and additional hydrodynamic load of the boat pool during the water entry and exit process. It is concluded that the increase of the Angle of the bottom edge of the boat can effectively reduce the adsorption force of the water and the flapping force of the water. At the same time, considering that the increase of the Angle of the bottom edge of the boat will cause the increase of the mass of the boat, the optimal Angle of the bottom edge of the boat is 4°. Guo Chao [21] et al established a local physical model of the ship lift car and the downstream approach channel of the Three Gorges ship lift with a scale of 1:12, carried out a hydraulic model test of the ship lift car, and analyzed the relationship between the force of the docking lock mechanism of the ship lift car and the ship draft, the speed of the ship lift car and the fluctuation of the water surface. Chen Yingying et al. [22] conducted a physical model test to study the hydraulic characteristics such as water surface fluctuation in the ship lift, ship subsidence and load of the butt locking mechanism during the ship's unloading process. It is concluded that from the perspective of docking safety of ship lift and navigation safety of ship lift, in order to meet the needs of 1,000-ton ships with a maximum draft of 2.4m, the design water depth of ship compartment is 3.5 m, and the ship's exit speed should be less than 0.7 m/s.

4. Numerical Model Test Research

Liao Lekang et al. [23] studied the dynamic performance of the wireline winch vertical ship lift system, derived the hydrodynamic pressure calculation formula of the ship lift during the trim movement, established the coupling dynamic model of the ship lift's trim movement and the torsion of the synchronous shaft of the main hoist, and analyzed the stability conditions and factors affecting the stability of the ship lift's trim movement. Wu Jianshan [24] used the finite element theory to calculate the hydrodynamic process of a ship moving in and out of the ship's carriage with variable speed on the basis of the two-dimensional shallow water wave equation. The dissipation term of the shallow water wave was given in the form of bottom friction. The fluctuation of water surface, velocity, pitch Angle, minimum distance between the bottom and the cabin, the total weight of the water body in the cabin and the dynamic moment of the water are analyzed during the process of entering and leaving the cabin. Wang Yingxue [25] proposed a shallow water wave equation containing not only the bottom friction term, but also the viscosity term, including the mass continuity equation, the conserved and non-conserved motion equations, and the pressure Poisson equation used to solve the ship bottom surface pressure. According to the design condition of the Three Gorges ship lift, the problems of sailing in and out of the ship compartment are calculated. The results show that the semi-piston effect will be produced when the ship moves in the compartment, and there will be water pile in front of the ship and water sink behind the ship. When the ship sails into the carriage, the ship will rise, when the ship sails out of the carriage, the ship will sink; The smallest gap between the ship and the hull is more likely to occur when the ship is moving out of the hull. Dong Junzhe et al. [26] used the finite element method to calculate the hydrodynamic characteristics of a ship in the process of entering and exiting the hull, as well as the heave, pitch and minimum distance between the ship and the bottom of the hull, according to the momentum conservation equation equalized by the shallow water characteristics in the vertical direction. Different from the traditional calculation method of two-dimensional shallow water wave equation, the author retains the viscosity term and generates the bottom friction term at the same time, which not only makes the numerical calculation more stable, but also makes the final mathematical equation more close to the real physical problem.

Zhou Ling [27] used CFD software Flow-3d to conduct a three-dimensional numerical simulation study on the process of exiting the ship, the maximum subsidence of the ship and the fluctuation characteristics of the water surface in the ship under different conditions of ship speed, ship depth and ship type, and concluded that the maximum subsidence of the ship is mainly related to speed, ship tonnage and ship depth. The effects of speed, tonnage and water depth on the fluctuation amplitude of water surface are similar to that of the ship's maximum subsidence. But comparatively speaking, speed has the most obvious influence on the fluctuation of water surface and the maximum sinking capacity of ship. Lin Zhe [28] first established a three-dimensional finite element model that can describe the operation process of the ship lift in accordance with the operating principle of the new escalator bidirectional hydraulic ship lift, and analyzed the problem of the ship lift's operating stability caused by water swaying in the ship lift's hull during the deceleration and braking stage through the numerical model. Xue Shu et al. [29] simulated the outflow process of the water conveyance system during the operation of the hydraulic ship lift by using a two-dimensional mathematical model, and determined the main influencing factors of the flow difference of the branch holes of the water conveyance system in the corridor of the hydraulic ship lift. Based on the effects of effective water depth and effective water width on the resultant dynamic water pulse pressure and convective pressure and their working height, Cold flight et al. [30] took the resultant dynamic water pressure calculated by the potential fluid model as reference to obtain the parameters in the expression of effective water depth and effective water width, and then obtained the modified Housner model, which was used for the analysis of the ship's dynamic characteristics. And the force analysis of ship compartment under dynamic load.

5. Conclusion

According to the above results of physical model tests on ship's hydrodynamics, it can be concluded that detailed studies have been conducted on specific issues such as the characteristics of water surface fluctuations in the ship's hull during the process of entering and exiting the ship's hull, the correlation between water surface fluctuations and ship's speed, etc. Relevant measured data and research results can also provide a good reference for the extension of this problem to the field of numerical simulation research.

Due to the particularity of ship movement in the ship compartment compared with other sailing states, the hydraulic characteristics in the ship compartment are more complicated, and the relevant researches mainly focus on two-dimensional numerical simulation. Therefore, it can be studied and developed in the direction of multi-dimensional numerical simulation.

Based on the above research and summary of many scholars at home and abroad, the current research on the hydrodynamics of ship entering and leaving the ship compartment is divided into two aspects: physical model test and numerical simulation, and physical model test is still the main research on the characteristics of water surface fluctuations during the process of ship entering and leaving the ship compartment. Therefore, more studies on numerical simulation of the hydrodynamics of ship entry and exit compartments are needed. In addition, there is a lack of specific research and analysis on the fluctuation characteristics of the water surface of vertical ship lift during the process of entering and leaving the ship compartment.

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